Multi-objective Power System Planning

Blagoja Stevanoski[1] and Arsen Arsenov[2]

Abstract – **This paper discusses a multi-objective optimization approach to generation expansion planning. Power system planning, nowadays, must deal with a wide range of options, with a large degree of uncertainty and with conflicting objectives due to the liberalization of the electricity market and increasing concern for the environmental impact. Multicriteria decision-making method is combines with conventional dynamic programming to compare different alternatives. Practical application of proposed approach concern the Macedonian electric system.**

Keywords – **Multiple criteria, uncertainty, risk, decision analysis, integrated resource planning**

I. Introduction

One of the basic objectives of power system planning is to determine the best possible investment options for the location, technology and timing of installing generation facilities, financing such investment and meeting satisfactory operation requirements in order to meet future demand for electricity over a planning horizon. The criteria, usually, are to minimize the total cost and maximize the reliability with different type of constraints. The total cost has two basic components: the investment cost given by construction cost of generating units and interconnection links and the operating cost associated to the fuel cost of the thermal system units.

The major complicating factors in such analysis include simultaneous consideration of demand side resources, uncertainties and risk management. Many planning factors are uncertain during planning process such as [7]:

- demand growth;
- fuel prices;
- interest and inflation rates;
- economic growth;
- environmental constraints;
- financial constraints;
- public opinion;

Etc.

The standard solution approach of the generation expansion problem in some planning models are deterministic by minimizing the total present worth of investment and operation costs subject to various types of constraints. The expansion plan is based on the best available forecasts and takes the optimal investment decision associated to the first stage of this plan (for example, the current year). This approach does not necessarily lead to the most adequate expansion strategy because an investment decision for the current stage is optimal under the assumption that the future conditions will occur as predicted. Used values for the model parameters, usually, are determined by more or less complex estimations. The problem with them is that these estimations have proved to be erroneous most of the times.

The other usual way of introducing uncertainty has been by probabilistic analysis. But, the degree of uncertainty may vary, ranging from items showing stochastic behavior within a known probability distribution to that exhibiting apparently chaotic behavior. Magnitudes may be known, but not frequency or timing and it is really difficult to assign probabilities to any of the different considered events. Although probabilistic analysis may be considered suitable for short-term uncertainties, it is certainly not the case for most uncertainties implied in a long-term planning process. For long-term uncertainties, we cannot assign probabilities, but rather possibilities.

Therefore, it becomes necessary to introduce in the decision making process a systematic and consistent treatment of these sources of uncertainty [7]. This task is very complex in metho-dological and computational terms. In contrast with “natural” uncertainty such as hydrological variation or equipment outages, many uncertainties mentioned above are dependent on economics and politics organization. Inclusion of environmental groups, industrial firms and consumer groups into the decision-making process related to environmental quality, reliability and cost of electricity, play a role in choosing a strategy to meet future electric demand. The fact that the decision process includes groups with such different viewpoints makes the choice of a single plan more difficult. This not only requires a wider scope in the methodological tools, but changes in the way results are presented. The concept of a “plan” as an expansion schedule is inadequate. It is necessary to have expansion strategies which take into account the “tree” of possible future scenarios and the dynamics of the decision making process.

The traditional objective function must be reformulate because the use of only one objective (usually cost) not adequate represent conflicting objectives such as, for example, economic costs and environmental impacts and etc.

Therefore, power system planning is decision process , which attempts to resolve multiple-conflicting objectives [2]. It is often not possible to identify a single plan, which simul-

[1]Blagoja Stevanoski is with the Faculty of Engineering, I. L. Ribar bb, 7000 Bitola, Macedonia, E-mail:blagoj.stevanovski@uklo.edu.mk

[2]Arsen Arsenov is with the Faculty of Electrical Engineering, Karpos II bb, 1000 Skopje, Macedonia, E-mail: aarsenov@etf.ukim.edu.mk

taneously optimizes all objectives. The solution is the selection of a “robust” plan, which may not be the best plan in some future, but is a good plan in most futures.

Uncertainty imposes risk and each type of uncertainty has different implication for decision-makers and analysts.

Risk management and evaluating of risk management strategies is now an important part of the integrated resource planning process [3]. Competitive forces are adding new risks that make responsible decision-making even more difficult. Planners are shifting from simply optimizing resource investments assuming a certain future to a different mode planning, assuming uncertainty.

Each type of uncertainty has different implication for decision-makers and analysts. At the broadest level, three classes of prescriptions exist. For uncertainties in the operating environment of the decision makers (uncontrollable exogenous variable) technical investigation is in order. For uncertainties about guiding values of the decision-makers (weighting factors on the objective function), consultation about policy priorities is needed. Finally, for uncertainties about future decisions on related agendas, coordination among actors is crucial.

II. Methodology

The framework and methodology presented in this paper accepts the reality that there is no optimal solution, in that the future is essentially unknowable. For these reason the framework is based on the comparative analysis of multiple scenarios concerning alternative futures. The framework allows the resource planner to utilize existing accepted planning and financial tools to develop the information upon which the trade-off analysis is based. High speed and inexpensive computational capabilities make the generation and evaluation of multiple scenarios possible

The methodology tries to integration the following characteristics [2]:

- considers multiple criteria;
- based on optimization techniques;
- takes into account the preferences of the different social interest group;

The core of the methodology is WASP III Plus production-cost simulation model developed by the International Atomic Energy Agency and the Argonne National Laboratory. Used in conjunction with other analytic methods, a wide range of options and uncertainties can be evaluated.

By evaluating how different supply strategies perform under a variety of possible futures, robust strategies can be identified. Capacity expansion strategies are evaluated against a range of possible changes in electric demand, fuel prices, and fuel availability. The comparative performance of various strategies over the range of possible future events identifies the most robust or least vulnerable strategies with respect to price, reliability, environmental emissions and other important measures.

The first phase of the proposed method [2] is the selection and characterization of technologies and fuels, both in the generation and demand sides, which may be available for the electricity system for the planning horizon.

The second step requires the generation of scenarios that incorporate all the uncertainties to which the planning process is subject (technical parameters, macroeconomic data, regulatory measures and etc.). Given the interrelation among many of these parameters, it should be possible to generate a small number of scenarios, which cover the whole range of uncertainties. These scenarios should be generated by means of interaction between analysts and decision-makers.

Than, the preferences of the decision-makers regarding the criteria considered have to be estimated using the analytic hierarchy process. It is based on a pairwise comparison of the criteria considered, and assignment of values for this comparison from a lexicographic scale. In addition, this method may be extended for the estimation of group preferences, for example by the weighted arithmetic mean method.

The preferences held by decision-makers may vary depending on the range of attribute values and therefore this information has to be presented to them before they elicit their preferences. The usual approach is to present them with payoff matrices. Payoff matrices are matrices where the values of the attributes of the problem are shown for the optimal solutions obtained for every one of the criteria considered. These matrices help understand the trade-off among conflicting criteria, and show the ideal and anti-ideal values for each of the attributes or criteria. Payoff matrices are built by running traditional single criteria optimization models for each of the criteria considered.

Once the criteria have been weighted, the generation of the efficient strategies for each scenario is undertaken by means of compromise programming theory. Compromise programming is based on the assumption that the preferred solution will be the one whose distance to the ideal point (the one in which all criteria considered reach their optimal level) is minimal.

The efficient strategies generated up may only be considered in an economic sense. When other uncertainties are introduced, it is necessary to incorporate risk analysis into the decision-making model.

III. Case Study

The multi-objective criteria were used to evaluate the relative impacts of some capacity expansion scenarios affecting to the development of Macedonian power system over a period of twenty year. The three criteria considered were:

- economic cost;
- fuel import vulnerability;
- risk of plant disaster;

At present, the major characteristic of Macedonian electric power system is domination of thermal power plants, which produced about 85% of total electricity demand. The whole installed capacity is 1440 MW distributed as fellows: (1) Steam power pants: 795 MW; (2) Fuel oil power plants 210 MW; (3) Hydroelectric power plants 435 MW [5].

As were described before, the first step of the proposed method consisted in selection and characterization of technologies and fuels expected to be available during planning period. The remaining reserves of coal and lignite fuel in Macedonia are quite limited. Additional coal-fired generating capacities are based on imported coal. There is a significant natural gas supply available through a pipeline from Ukraine and Russia. Several types of gas-fired thermal power plants are considered as candidates. Nuclear power is also considered as one of the potential long-term option for electricity generation. The new capacity thermal units are described in Table 1.

Table 1. Thermal Candidate Units

Name	Net Capacity (MW)	Fuel Cost ($/GJ)	Overnight Cost ($/kW)	Fuel Type
Bitola Rehabilitation	207	1,42	810	Lignite
Imported Coal	207	1,78	1450	Lignite
Gas Turbine (GT)	122	2,86	280	Natural Gas
Combined Gas Turbine	220	2,86	620	Natural Gas
Cogeneration (COGN)	175	2,86	670	Natural Gas
Nuclear	323	0,43	1860	Uranium

The second step consisted on the generation of small, but consistent number of scenarios, which might account for the uncertainty related to socio-economic aspects. The generation of scenarios was based, mostly on rehabilitation of thermal power plants “Bitola”, imported coal and involved a natural gas-fired plants. For this planning exercise three presumed scenarios were considered: Power engineers scenario (Case I), Energy economist scenario (Case II) and Public scenario (Case III).

As was mention above, three criteria was considered: (1) Costs as a total present worth cost including capital, fuel and O&M cost; (2) Fuel import vulnerability as a cumulative power production (MWh) for each fuel type and (3) Risk of plant disaster as a cumulative installed capacity (MW) [1]. In order to obtain the preference weights from each social interest group the trade-off was done between attributes for the different scenarios considered. This was done by using of the payoff matrices, which were build with a single criteria classical generation expansion model, by which the optimal solution for each of the three criteria considered was determined. Each group compared different criteria and thus the individual preferences were obtained. This individual preferences were aggregated using the weighted arithmetic mean method and are presented in Table 2.

Table 2. Relative weights among preferences

	Cost	Plant disastrous risk	Fuel import vulnerability
Power engineers	0,66	0,21	0,13
Nuclear engineers	0,68	0,15	0,17
Energy economists	0,75	0,11	0,16
Public	0,35	0,52	0,13

When the preferences given before were introduced into the multiple-criteria optimization model, the different efficient solutions under every scenario were obtained. The multiple-criteria optimization model was basically a classical generation expansion model in which the objective function was formed by adding all the objectives considered, previously normalized and weighted, according to the compromise programming theory.

As should be expected, the introduction of additional criteria (besides from economic costs) generates a more expensive solution depending on the preferences of the decision maker groups toward the balance between these conflicting objectives.

It is important to note that this solution will be modified when other uncertainties are introduced into the analysis, in such a way that the efficient strategies will be different under different scenarios. The determination of which of these efficient strategies is the best requires evaluating their behavior under every scenario considered and using a decision rule, which incorporates the attitude of the decision-maker toward risk. The optimal strategies for each scenario, first, should be obtained, for each set of decision-maker preferences. As an example, the values of attri-butes of the optimal planning strategies for power engineers set of preferences, under each of scenarios are presented in Table 3.

Table 3. Attributes for the optimal strategies under each

	Cost 10^6 ($)	Plant disastrous risk (MW)	Fuel import vulnerability 10^3 (MWh)
Case I	1719	2681	156
Case II	1772	2590	142
Case III	1854	2825	135

The values of the different attributes are different across the considered scenarios. This reflects that the optimal expansion under one scenario may be bad one under another. To select robust strategies was used decision theory (the Savage criterion) which minimizes regret across all scenarios. Regret was calculates as the Manhattan distance between the studied solution and the ideal solution for each scenario. The

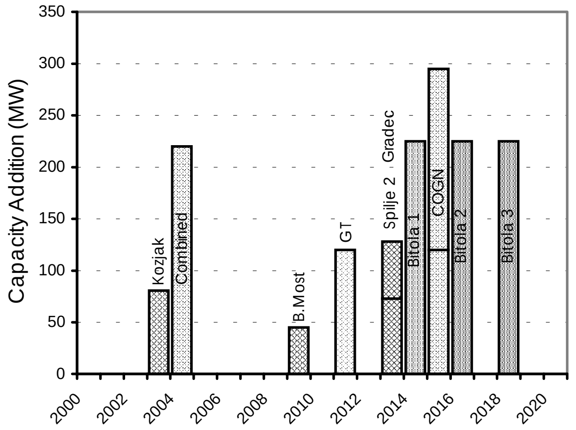

Fig. 1. Optimal expansion plan for the Case I

most robust strategy for power engineers weights is shown in Fig. 1.

IV. Conclusion

The use of a multiple criteria in power system planning process is useful in assessing how different options are suited to preparing for an uncertain future. Different perceptions of relative value of competing attributes allows decision-makers to weigh and constructively discuss trade-off associated with any one decision.

This model incorporates the preferences of different groups of decision-makers, so that the results of the model may be interpreted in terms of the preferences of society toward these conflicting objectives. The results obtained from the multiple-criteria model are assessed under scenarios, which cover a full range of uncertainties. By the application of classical decision rules, such as the Wald or Savage criteria, the most flexible and robust strategy can be obtained.

Results shown that the application of this methodology achieves large reduction in risk with small increments in cost, while allowing the society to express their preferences toward any of the risk considered.

In order to ensured the flexibility and robustness of the solution, a detailed study should be performed and a large number of scenarios should be generating by expanding the set of option and uncertainties, particularly a more explicit treatment of demand-side management alternatives.

References

[1] H.T. Yang, S.L. Chen, “Incorporating a multi-criteria decision procedure into the combined dynamic programming/production simulation algorithm for generation expansion planning”, IEEE Trans. on Power systems, Vol.4, No.1, pp. 165-174, 1989.

[2] P. Linares, “Multiple criteria decision making and risk management tools for power system planning”, IEEE Trans. on Power systems, Vol.17, No.3, pp. 895-900, 2002.

[3] C.J.Andrews, “Evaluating Risk Management Strategies in Resource Planning”, IEEE Transaction on Power systems, Vol.10, No.1, pp. 420-426, 1995.

[4] S.Majumdar, D.Chattopadhyay, “A Model for Integrated Analysis of Generation Capacity Expansion and Financial Planning”, IEEE Transaction on Power systems, Vol.14, No.14, pp. 466-471, 1999.

[5] ***, “Eksperten elaborat za razvoj na energetikata i energetskata infrastruktura vo Republika Makedonija do 2020 god”, AD EMO-Ohrid, Institut za energetika, Skopje, 1999.

[6] W.J.Burke, F.C.Schweppe, B.E.Lowell, M.F.McCoy, S.A.Monohon, “Trade off methods in system planning”, IEEE Trans. on Power systems, Vol.3, No.3, pp. 1284-1290, 1988.

[7] B.G.Gorenstin, N.M.Campodonico, J.P.Costa, M.V.Pereira, “Power system expansion planning under uncertainty”, IEEE Trans. on Power systems, Vol.13, No.1, pp. 129-136, 1993.

[8] R.D.Tabors, S.R.Connors, C.G.Bespolka, “A Framework for Integrated Resource Planning: The Role of Natural Gas Fired Generation in New England”, IEEE Transaction on Power systems, Vol.4, No.3, pp. 1010-1016, 1989.

[9] M.Yehia, R.Chedid, M.Ilic, A.Zobian, R.Tabors, J.Lacalle-Melero, “A Global Planning Methodology for Uncertain Environments: Application to the Lebanese Power System, IEEE Transaction on Power systems, Vol.10, No.1, pp. 332-338, 1995.

[10] E.O.Crousillat, P.Dorfner, P.Alvarado, H.M.Merrill, “Conflicting Objectives and Risk in Power System Planning”, IEEE Trans. on Power systems, Vol.8, No.3, pp. 887-893, 1993.

[11] B.F.Hobbs, P.M.Meier, “Multicriteria Methods for Resource Planning: An Experimental Comparation”, IEEE Transaction on Power systems, Vol.9, No.4, pp. 1811-1817, 1994.

[12] P.S.Neelakanta, M.H.Arsali, “Integrated Resource Planning Using Segmentation Method Based Dynamic Programming”, IEEE Transaction on Power systems, Vol.14, No.1, pp. 375-385, 1999.